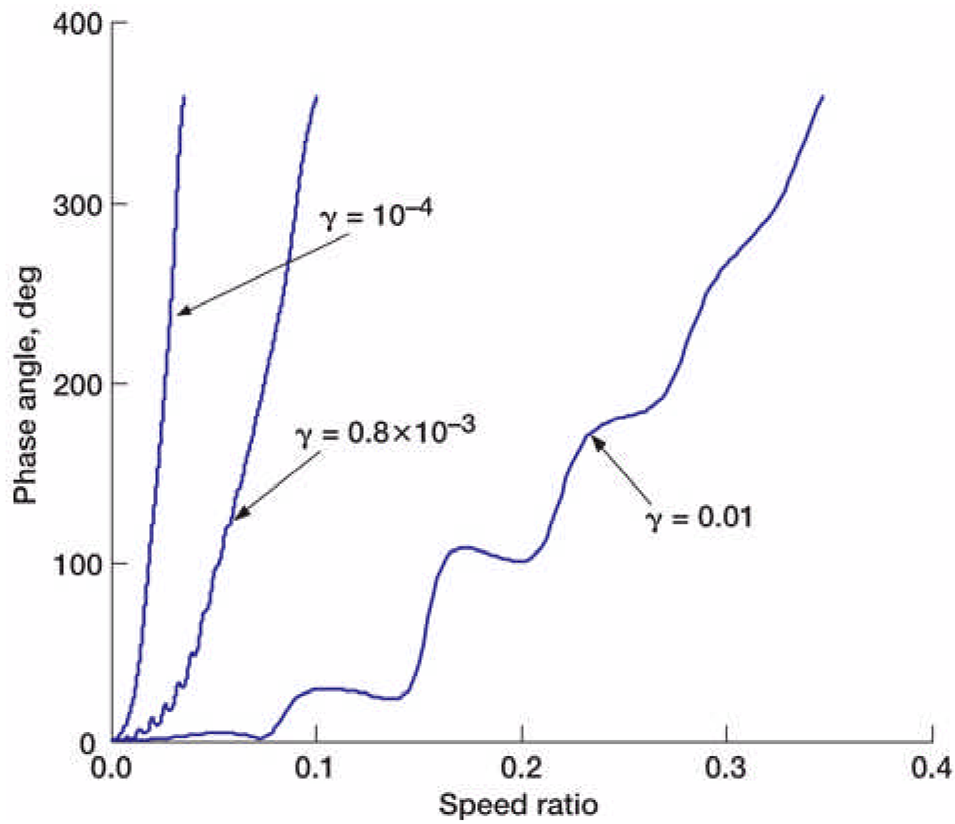
Vibration-Based Method Developed to Detect Cracks in Rotors During Acceleration Through Resonance

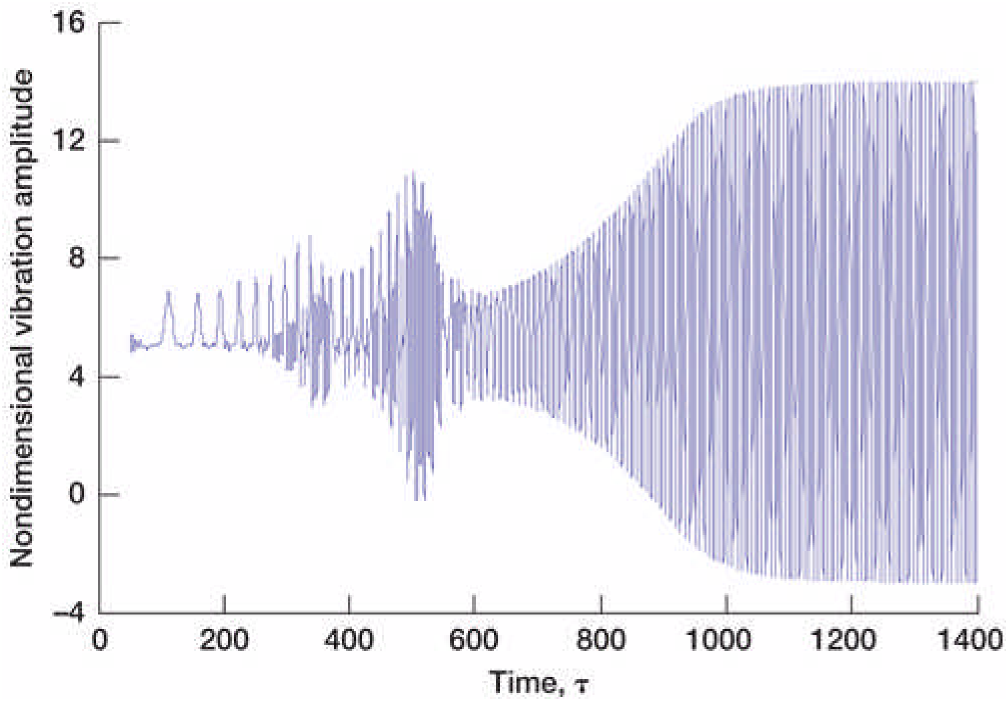
In recent years, there has been an increasing interest in developing rotating machinery shaft crack-detection methodologies and online techniques. Shaft crack problems present a significant safety and loss hazard in nearly every application of modern turbomachinery. In many cases, the rotors of modern machines are rapidly accelerated from rest to operating speed, to reduce the excessive vibrations at the critical speeds. The vibration monitoring during startup or shutdown has been receiving growing attention (ref. 1), especially for machines such as aircraft engines, which are subjected to frequent starts and stops, as well as high speeds and acceleration rates. It has been recognized that the presence of angular acceleration strongly affects the rotor's maximum response to unbalance and the speed at which it occurs. Unfortunately, conventional nondestructive evaluation (NDE) methods have unacceptable limits in terms of their application for online crack detection. Some of these techniques are time consuming and inconvenient for turbomachinery service testing. Almost all of these techniques require that the vicinity of the damage be known in advance, and they can provide only local information, with no indication of the structural strength at a component or system level. In addition, the effectiveness of these experimental techniques is affected by the high measurement noise levels existing in complex turbomachine structures. Therefore, the use of vibration monitoring along with vibration analysis has been receiving increasing attention.

A new analytical model for detecting shaft cracks was developed (refs. 2 and 3) on the basis of the Jeffcott rotor model with transverse crack assumed at the middle of the shaft. The criterion for the opening and closing of the crack were based on the angle between the crack centerline and the shaft vibration vector, so the rotor weight-dominance assumption can be ignored. The stiffness-weakening effects of a cracked rotor in both the strong and weak axes were taken into consideration for deep cracks.



Phase angle of the accelerated rotor passing through the critical speed for angular acceleration ratios, •, of 0.01, 0.8×10^{-3}, and 10^{-4}; •, crack depth, 0.4.

The nonlinear responses of a rotor passing through the critical speed with several values of constant angular acceleration ratios • and different crack depths • *K* were evaluated. For all cases, we assumed that the damping ratio • was 0.05 and the normalized unbalance eccentricity was 0.05. The preceding graph presents the change in the rotor phase response due to the acceleration and crack. In general, a crack causes the amplitude of the phase response to decrease for the given speed ratio and acceleration rate. It induces significant oscillations in the rotor phase response, especially for higher acceleration rates. The characteristic "saw-cut" pattern of the phase waveform can be used in the online crack-detection systems.



Time history of normalized vibration amplitude for a rotor with a crack with a nondimensional crack depth, • K, of 0.25 at the stalled condition for a nondimensional driving torque, T, of 0.001.

This graph illustrates the response of a cracked rotor subjected to constant torque, when the rotor was locked in the stalled condition; that is, it failed to accelerate beyond the critical speed. For this case, the normalized unbalance eccentricity was assumed to be 0.85×10^{-3}, the nondimensional weight of the rotor was 5, and the damping ratio • was 0.005. The crack caused one-third and one-half subharmonic peaks in the rotor response and significantly increased the fundamental vibration response of the "stalling" rotor. In this case, the large vibration amplitudes of the stalling cracked rotor might well have exceeded the rotor static deflection and, therefore, violated the common weight dominance assumption made in the study of rotors with breathing cracks. It was shown that for the stalled rotor the maximum vibration amplitude grows parabolically as the crack depth increases and the corresponding rotor stalling speed decreases almost linearly. We plan to verify these results experimentally.

References

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